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SAILING ALL POINTS OF THE COMPASS

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Abstract

Hammitt, Phillips, Barkla, Pierson, and Bauer have each expressed the idea that a windmill-driven boat could be used to sail on all points of the compass, perhaps as well as or better than a conventional sail-powered craft. The windmill-driven boat is shown to have essentially the same propulsive force mechanism as that of the conventional sailboat so that neither type of vehicle is inherently better than the other.

1. INTRODUCTION

The spirit of The Ancient Interface, as sponsored by the Los Angeles and the Orange County Sections of the AIAA, has been to apply modern technology to the art of sailing. Within this spirit a number of papers concerning the fundamentals of sailing propulsion have been presented. These papers have more in common than first meets the eye. Therefore, this brief survey has been assembled with the hope that these concepts may be illuminated.

Hammitt[1] has discussed the fundamentals of wind propulsion. He has calculated power coefficients in frictionless flow for both the conventional sail and for a windmill used to generate the propulsive power. These power coefficients are given for the optimum loading of the sail or windmill as a function of the angle γ between the boat velocity vector $\vec{V}_S$ and the true wind vector $\vec{V}_T$[2,3,4,5]. The power coefficients are also a function of the ratio of boat speed to wind speed V_S/V_T. These parameters are illustrated in Figure 1. Hammitt's

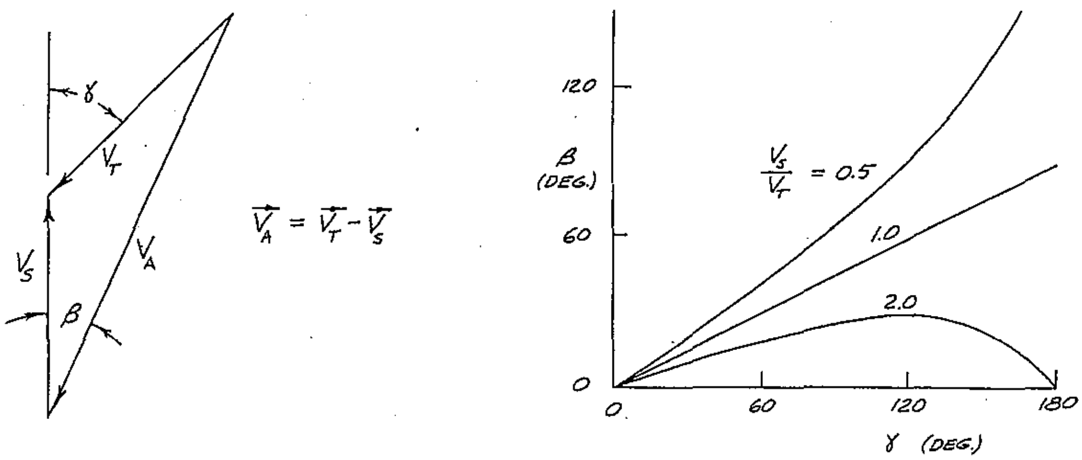

Figure 1. Relation between ship speed V_S, true wind speed V_T, apparent wind speed V_A, true heading γ, and apparent heading β.

calculations show the well-known fact that the power coefficient of a conventional sail goes to zero, even in frictionless flow, as γ goes to zero. On the other hand, for the windmill the power coefficient at γ near zero is very large, and it becomes small only as γ goes to 180 degrees, assuming that $V_S/V_T \leq 1$. Since the capability for sailing all points of the compass would be desirable, and since only the windmill powered ship can do this, does this mean that windmill-driven ships should be developed? Johnson(6) has suggested that this question might be at least partially answered if someone would work up a proof that the conventional sail-driven vehicle is more efficient than the windmilling vehicle. This paper has been written for the purpose of discussing the general nature of the relationship between windmill-driven and sail-driven ships.

2. A NEW TYPE OF SAILING VEHICLE

In order to show the related nature of windmill-driven and sail-driven ships, a new type of sailing vehicle has been invented, here called the "windsail," as illustrated in Figure 2. The windsail can be operated as either a windmill-driven or a sail-driven ship. Two hulls are used for lateral stability, and a long structural member, called boom A, extends ahead of the hulls. Attached to these booms is a spreader bar, and booms B are mounted on each end of the spreader bar. The booms B are free to rotate in a horizontal plane about the ends of the spreader bar. Each of these two booms carries a mast, a sail, and a keel.

This description should make obvious the point that the windsail may be operated in the manner of an ordinary sailboat by tying down the booms B so that they cannot move laterally. Then the sails may be trimmed for any sailing point between close hauled and running.

The so-called windmill mode of operation is novel and best illustrated by supposing that the ship is headed directly windward. The booms B are now freed to move laterally. To make windward progress the sails are first set as illustrated in Figure 3a. The sail force vectors F then move the sails away from the hulls. The forces F are balanced by the keel hydrodynamic forces, which have a forward component that drives the hulls forward at speed V_S, and the sails, keels and masts move with the velocity vectors $\vec{V}_M$, as shown in Figure 3a. The process is simply just like that of two independent sailboats sailing close-hauled but on opposite tacks with respect to the wind, but the boats are linked to the two hulls which are pulled along directly to windward.

Clearly this process can continue for only a short period before the masts and booms B are swung near the physical limits of their travel. Then the sails and keels must be retrimmed for the opposite tack, as shown in Figure 3b. This tack may continue for only a short time before the sails approach the hulls so closely that the tack of Figure 3a must be repeated. Thus, progress directly to windward requires a change in tack for every few hull lengths of travel.

This mode of operation is called the windmill mode inasmuch as the sail moves in the same manner with respect to the wind as does a windmill blade element. Furthermore, the keel operates with respect to the water in the same manner as that of a water propeller. Thus, in the windmill mode, the windmill vehicle operates to windward on exactly the same sort of aerodynamic and hydrodynamic forces as do the various forms of windmill-powered ships described by Phillips(7), Barkla(8), Pierson(9), and Bauer(10).

The tacking described above is directly analogous to periodically changing the direction of rotation of the windmill and propeller on a ship such as described by Phillips, Barkla, Pierson, or Bauer. Of course, there is no need to change the direction of rotation on these ships; to do so would be quite cumbersome and restrictive in the design of the blade elements. On the other hand, the windsail is forced to tack because of physical constraints. However, the windsail vehicle is not necessarily a more cumbersome vehicle than the others(7,8,9,10). We may note that the windsail has a much more efficient "transmission" than do the other

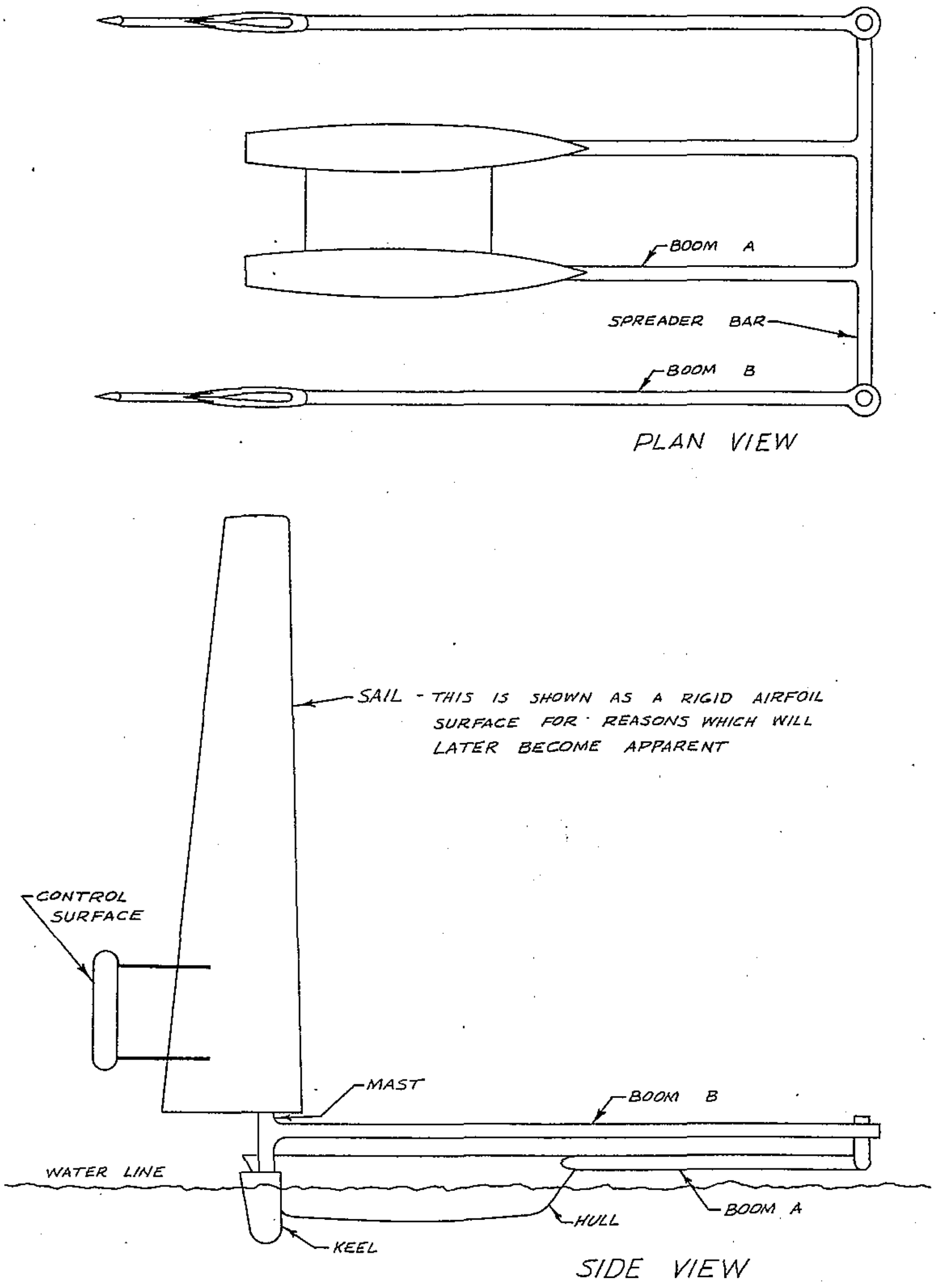

Figure 2. Schematic diagram of a "windsail."

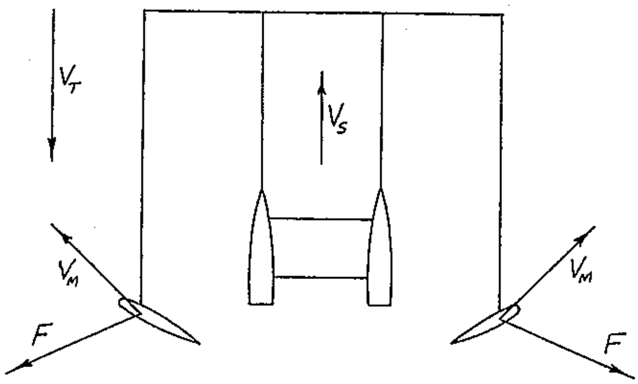

Figure 3a. Sailing directly to windward with masts moving away from the hulls.

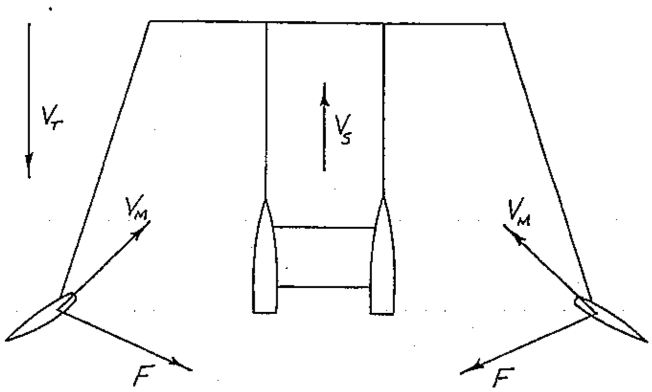

Figure 3b. Sailing directly to windward with masts moving toward the hulls.

boats(7,8,9,10). This transmission is just the mast which connects the sail and the keel. This simplicity eliminates most of the transmission losses, whereas transmission losses from shafting and gearing can be quite significant(7,8,9,10). Thus, the windsail configuration or "linear windmill"(11) is different from the earlier windmill power concepts through mechanical constraints rather than any fundamental change in the hydrodynamic and aerodynamic forces which generate the propulsive energy.

In sailing directly downwind the windsail can, of course, be operated in the manner of a conventional sailboat, which means that V_s must always be less than V_T. Nevertheless, it is quite possible to increase V_s to faster than the wind speed(10) V_T by operating the windsail in the so-called windmill mode. This is illustrated by the vector diagram, Figure 4, which shows one mast velocity vector $\vec{V}_M$ on one of the two tacks. The hull speed V_s, which is equal to $-V_M \cos \gamma_M$, is greater than V_T. That the forces are in balance so that this speed can be maintained is shown on the force vector diagram, where F is the total sail force and H is the total keel force. These forces are at an angle of $90° + \varepsilon$ with respect to the apparent wind and apparent water speeds, V_A and $-V_M$, respectively, where ε is the so-called drag angle. The sum of $\vec{F}$ plus $\vec{H}$ is given by $\vec{R}$; this is the force which balances the hull drag and/or the vehicle

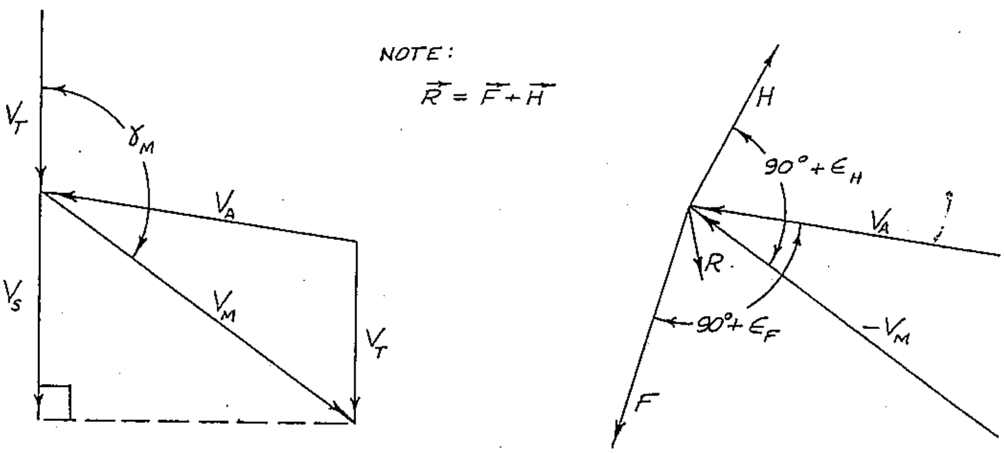

Figure 4. Vector diagrams describing the windsail going directly downwind faster than the wind.